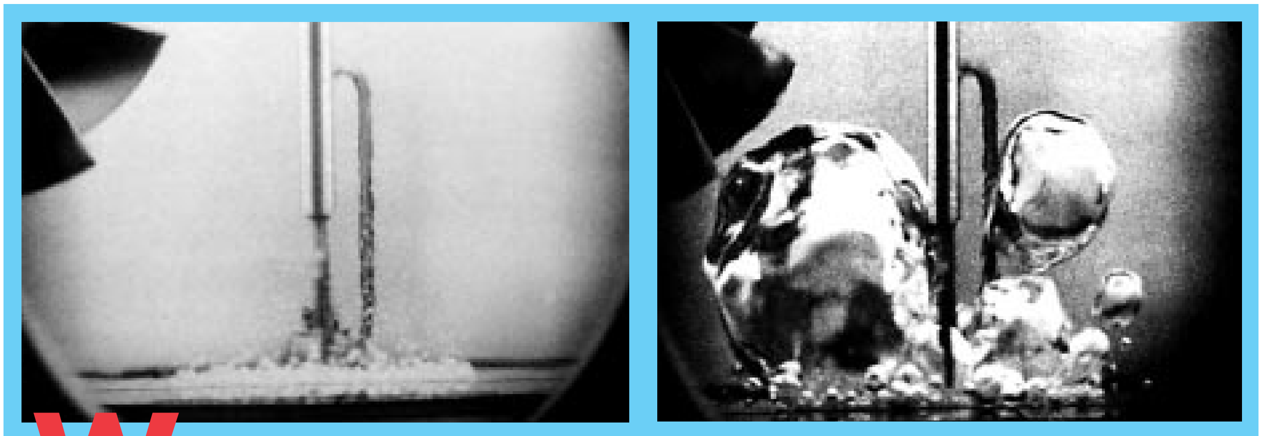
Fluid Physics



What Is Fluid Physics?

A fluid is any material that flows in response to an applied force; thus, both liquids and gases are fluids. Some arrangements of solids can also exhibit fluid-like behaviors: granular systems (such as soil) can respond to extraordinary forces, like those induced by earthquakes or floods, with a flow-like shift in the arrangement of solid particles and the air pockets or liquids that fill the spaces between them. Fluid physicists seek to better understand the physical principles governing fluids, including how fluids flow under the influence of energy, such as heat or electricity; how particles and gas bubbles suspended in a fluid interact with and change the properties of the fluid; how fluids interact with solid boundaries; and how fluids change phase, either from fluid to solid or from one fluid phase to another. Fluid phenomena studied range in scale from microscopic to the size of the atmosphere and include everything from the transport of cells in the human body to changes in the composition of the atmosphere.

The universal nature of fluid phenomena makes their study fundamental to science and engineering. Understanding the fluid-like behavior of soils under stress will help civil engineers design safer buildings in earthquake-prone areas. Materials engineers can benefit from a better grasp of how the structure and properties of a solid metal are determined by fluid behavior during its formation. And knowledge of the flow characteristics of vapor-liquid mixtures is useful in designing power plants to ensure maximum stability and performance. NASA's microgravity fluid physics program seeks to use the microgravity environment to improve scientists' understanding of fluid behavior. (See back page for more information on microgravity, or µg.)

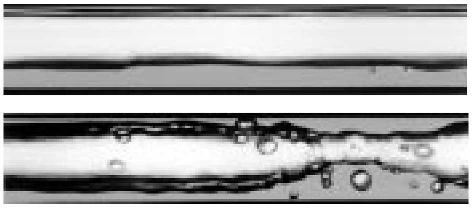
The work of fluid physics researchers often applies to the work of other microgravity scientists. Materials science researchers rely on the knowledge of principles of fluid physics for materials processing. For example, impurities in materials such as glasses and alloys can be reduced by managing fluid behavior while the material is in a molten state. This is desirable because impurities may degrade sought-after properties of materials, such as corrosion resistance, mechanical toughness, and optical transmissivity. In addition, knowledge of fluid flow in microgravity can help combustion scientists improve fire safety and fuel efficiency.

Lewis Research Center in Cleveland, Ohio, is NASA's Microgravity Center of Excellence for fluid physics.

On the cover: When a liquid is heated from the bottom to the boiling point in Earth's gravity (left photo), small bubbles of heated gas form near the bottom of the container and are carried to the top of the liquid by gravity-driven convective flows. In the same setup in microgravity (right photo), the lack of convection and buoyancy allows the heated gas bubbles to grow larger and remain attached to the container's bottom for a significantly longer period.

Why Conduct Fluid Physics Research in Microgravity?

Gravity strongly affects many fluid physics phenomena by creating forces in fluid systems that drive motions, shape boundaries, and compress fluids. One significant gravity-driven motion is buoyancy-induced flow, in which lighter, less dense molecules flow toward the top of a liquid as denser molecules fill in at the base of the liquid. An example of this type of flow can be found in boiling water, in which heated air bubbles float to the top as cooler, denser water flows to the bottom. Sedimentation, another gravity-driven phenomenon, occurs when fluids of unequal densities separate into distinct layers, with the densest settling at the bottom and the least dense rising to the top. In microgravity, the effects of the gravity-driven processes of sedimentation and buoyancy-induced flow are nearly eliminated. The absence of these phenomena allows scientists to observe other phenomena that are present under the influence of Earth's gravity, but usually obscured.



These photos show side views of water and air flowing through clear pipes. The top photo illustrates that in Earth's gravity, the air rises and forms a layer on top of the water because gases are less dense than liquids. The bottom photo shows that in microgravity, density differences are irrelevant, and the air can form a core flowing through the center of the pipe, surrounded by water.

Fluid Physics Research Areas

Complex Fluids

This research area focuses on the unique properties of complex fluids, which include colloids, gels, magneto-rheological fluids, foams, and granular systems.

Colloids are suspensions of finely divided solids or liquids within fluids (liquids or gases). Some examples of colloidal dispersions are aerosols (liquid droplets in gas), smoke (solid particles in gas), and paint (solid particles in liquid). Gels are colloidal mixtures of liquids and solids in which the solids have linked together to form a continuous network, becoming very viscous (resistant to flow).

Magneto-rheological fluids consist of suspensions of colloidal particles. Each particle contains many tiny, randomly oriented magnetic grains that can be oriented into chains by an externally applied magnetic field. These chains may further coalesce into larger-scale structures in the suspension, thereby dramatically increasing the viscosity of the suspension. This increase, however, is totally reversed when the magnetic field is turned off.

A foam is a nonuniform dispersion of gas bubbles in a relatively small volume of liquid that contains surface-active macromolecules, or surfactants (agents that break down the surface tension of liquids). Foams have striking properties in that they are neither solid, liquid, nor vapor, yet they exhibit features of all three. Important uses for custom-designed foams include detergents, cosmetics, foods, fire extinguishing, oil recovery, and many physical and chemical separation techniques. Unintentional generation of foam, on the other hand, is a common problem affecting the efficiency and speed of a vast number of industrial processes involving the mixing or agitation of multicomponent liquids. It also occurs in polluted natural waters and in the treatment of wastewater. In all cases, control of foam stability and rheology (deformation or flow in response to an external force) is required.

Examples of granular systems include soil and polystyrene beads, which are often used as packing material. Granular systems are made up of a series of similar objects that can be as small as a grain of sand or as large as a boulder. Although granular systems are primarily composed of solid particles, their behavior can be fluid-like. The strength of a granular system is based upon the friction between and the geometric interlocking of individual particles, but under certain forces or stresses, such as those induced by earthquakes, these systems exhibit fluidic behavior.

This colloidal system is a model used to study the fundamentals of solidification. In the photos above, a colloidal mixture of hard spheres dispersed in a liquid has started to form crystals. As the crystallites grow on Earth (left photo), they become heavier and fall to the bottom of the liquid, which disturbs their growth. When the experiment is performed in microgravity (right photo), the crystallites remain suspended in the liquid and grow much larger.

Studying complex fluids in microgravity allows for the analysis of fluid phenomena that are often masked by the effects of gravity. For example, researchers are particularly interested in the phase transitions of colloids, such as when a liquid changes to a solid. These transitions are easier to observe in microgravity. Foams, which are particularly sensitive to gravity, are more stable (and can therefore be more closely studied) in microgravity. In magneto-rheological fluids, controlling rheology induced by a magnetic field has many potential applications, from shock absorbers and clutch controls for cars to robotic joint controls. Under the force of Earth's gravity, the magnetic particles in these fluids often fall out of suspension, but in microgravity, this problem is eliminated. Investigations of the behavior of granular systems, which have previously been hampered by Earth's gravity, are more feasible in microgravity because the systems do not settle as they do on Earth.

Multiphase Flow and Heat Transfer

This research area, which has applications in the engineering of heat transfer systems and gas purification systems, focuses on complex problems of fluid flow in varying conditions. Scientists are seeking to add to their currently limited knowledge of how gravity-dependent processes, such as boiling and steam condensation, occur in microgravity. Boiling is known to be an efficient way to transfer large amounts of heat, and as such, it is often used for cooling and for energy conversion systems. In space applications, boiling is preferable to other types of energy conversion systems because it is efficient and because the apparatus needed to generate power is smaller.

Another of the mechanisms by which energy and matter (atoms, molecules, particles, etc.) move through liquids and gases is diffusive transport. The way atoms and molecules diffuse through a liquid or gas is due primarily to differences in concentration or temperature. Researchers use microgravity to study diffusion in complex systems, a process that would normally be eclipsed by the force of gravity.

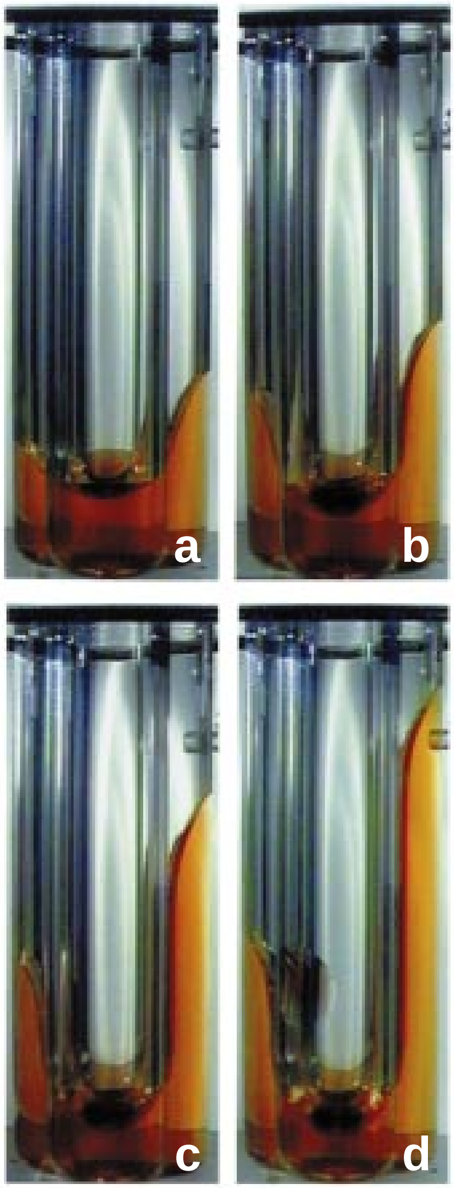
Understanding the physics of multiphase flow and heat transfer will enable scientists to extend the range of human capabilities in space and will enhance the ability of engineers to solve problems on Earth as well. Applications of this research may include more effective air conditioning and refrigeration systems and improvements in power plants that could reduce the cost of generating electricity.

Interfacial Phenomena

Research in this area focuses on how an interface, like the boundary between a solid and a liquid, acquires and maintains its shape. Interface dynamics relate to the interaction of surfaces in response to heating, cooling, and chemical influences. A better understanding of this topic will contribute to improved materials processing and other applications.

Interfacial phenomena, such as the wetting and spreading of two immiscible liquids or the spreading of a fluid across a solid surface, are ubiquitous in nature and technology. Duck feathers and waterproof tents repel water because the wetting properties of the surfaces of their fibers prevent water from displacing the air in the gaps between the fibers. In contrast, water spontaneously displaces air in the gaps of a sponge or filter paper. Technologies that rely on dousing surfaces with fluids like agricultural insecticides, lubricants, or paints depend on the wetting behavior of liquids and solids. Wetting is also a dominant factor in materials processing techniques, including film and spray coating, liquid injection from an orifice, and crystal growth. Interfaces dominate the properties and behavior of advanced composite materials, where wetting of the constituent materials dictates the processing of such materials. Understanding and controlling wetting and spreading poses both scientific and technological challenges.

In reduced gravity, wetting determines the configuration and location of fluid interfaces, thus greatly influencing, if not dominating, the behavior of multiphase fluid systems. This environment provides scientists with an excellent opportunity to study wetting and surface tension forces that are normally masked by the force of Earth's gravity. The information obtained from this research can also help improve the design of space engineering systems strongly affected by wetting, including liquid-fuel supply tanks, two-phase heat transfer and/or storage loops, and fluids management devices for life support purposes.



This series of photos was taken during a run of the Interface Configuration Experiment on the second United States Microgravity Laboratory (USML–2). They show a change over time in the shape of the interface between a liquid and a gas in a sealed, slightly asymmetrical container. Under the force of Earth's gravity, the interface would remain nearly flat, but in microgravity, the interface shape and location changes significantly in the container, resulting in major shifts of liquid arising from small asymmetries in the container shape. This phenomenon can be used to pump or redirect a liquid by varying the geometry of its container.

Dynamics and Stability

This broad area of research includes drop dynamics, capillarity, and magneto/electrohydrodynamics.

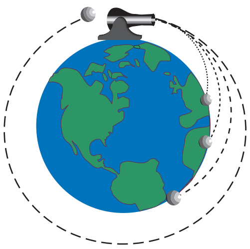
Drop dynamics research deals with the behavior of liquid drops and gas bubbles under the influence of external forces and chemical effects. This research provides a foundation for understanding scientific and technological areas in which drops and bubbles have a role, from rain in the atmosphere to chemical processes.

Scientists are also interested in studying single bubbles and drops as models for other natural systems. The perfect spheres formed by bubbles and drops in microgravity (due to the dominance of surface tension forces) are an easy fit to theoretical models of behavior — fewer adjustments need to be made for the shape of the model. Investigators can manipulate the spherical drops using sound and other impulses, creating an interactive model for processes such as atom fissioning.

Capillarity refers to a class of effects that depend on surface tension. The shape a liquid assumes in a liquid-liquid or liquid-gas system is controlled by surface tension forces at the interface. Small disturbances in the balance of molecular energies at these boundaries or within the bulk of the liquid can cause shifts in the liquid's position and shape within a container (such as a fuel tank) or in a containing material (such as soil). These changes, or capillary effects, often occur in liquids on Earth, but are to some degree masked or minimized by the stronger force of gravity. In microgravity, however, capillary effects become prominent. The study of capillary phenomena in microgravity will enable researchers to better understand and predict fluid configurational changes both on Earth and in low-gravity environments.

Microgravity fluid physics researchers also study the effects of magnetic and electric fields on fluid flows, or magneto/electrohydrodynamics. Promising microgravity research subjects in this area include weak fluid flows, such as those found in poorly conducting fluids in a magnetic field, and Joule heating, which is heating a material by flowing an electric current through it. In Earth's gravity, Joule heating causes buoyancy-driven flows that, in turn, obscure its effects. In microgravity, however, buoyancy-driven flows are nearly eliminated, so researchers are not only able to study the effects of Joule heating, but they can also observe other processes involving applied electric fields. An example of such processes is electrophoresis, which is the use of electric fields to separate biological materials.

Gravity and Microgravity



In his "thought experiment," Isaac Newton hypothesized that by placing a cannon at the top of a very tall mountain and firing a cannonball at a high enough velocity, the cannonball could be made to orbit the Earth.

Gravity is such an accepted part of our lives that we rarely think about it, even though it affects everything we do. Any time we drop or throw something and watch it fall to the ground, we see gravity in action. Although gravity is a universal force, there are times when it is not desirable to conduct scientific research under its full influence. In these cases, scientists perform their experiments in microgravity — a condition in which the effects of gravity are greatly reduced, sometimes described as "weightlessness." This description brings to mind images of astronauts and objects floating around inside an orbiting spacecraft, seemingly free of Earth's gravitational field, but these images are misleading. The pull of Earth's gravity actually extends far into space. To reach a point where Earth's gravity is reduced to one-millionth of that on Earth's surface, one would have to be 6.37 million kilometers away from Earth (almost 17 times farther away than the Moon). Since spacecraft usually orbit only 200–450 kilometers above Earth's surface, there must be another explanation for the microgravity environment found aboard these vehicles.

Any object in freefall experiences microgravity conditions, which occur when the object falls toward the Earth with an acceleration equal to that due to gravity alone (approximately 9.8 meters per second squared [m/s^2], or 1 g at Earth's surface). Brief periods of microgravity can be achieved on Earth by dropping objects from tall structures. Longer periods are created through the use of airplanes, rockets, and spacecraft. The microgravity environment associated with the space shuttle is a result of the spacecraft being in orbit, which is a state of continuous freefall around the Earth. A circular orbit results when the centripetal acceleration of uniform circular motion ($\mathbf{v}^2/\mathbf{r}$; $\mathbf{v}$ = velocity of the object, $\mathbf{r}$ = distance from the center of the object to the center of the Earth) is the same as that due to gravity alone.

Microgravity Research Facilities

A microgravity environment provides a unique laboratory in which scientists can investigate the three fundamental states of matter: solid, liquid, and gas. Microgravity conditions allow scientists to observe and explore phenomena and processes that are normally masked by the effects of Earth's gravity.

NASA's Microgravity Research Division (MRD) supports both ground-based and flight experiments requiring microgravity conditions of varying duration and quality. These experiments are conducted in the following facilities:

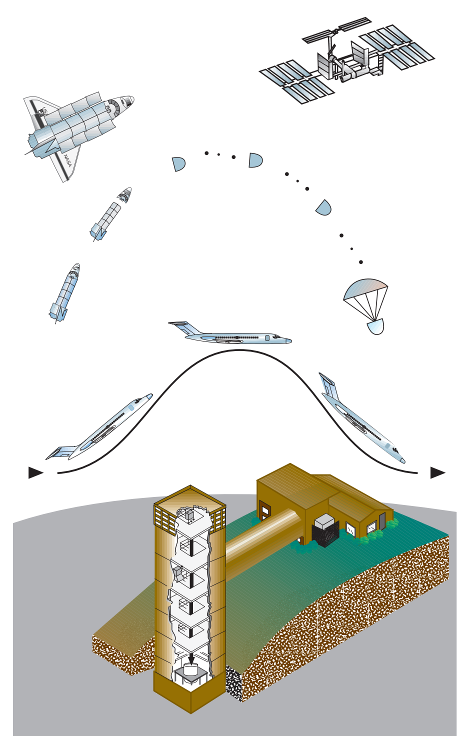
A **drop tower** is a long vertical shaft used for dropping experiment packages, enabling them to achieve microgravity through freefall. Various methods are used to minimize or compensate for air drag on the experiment packages as they fall. Lewis Research Center in Cleveland, Ohio, has two drop facilities (one 24 meters tall and one 132 meters deep) that can accommodate experiments which need only a limited amount of time (2.2 or 5.2 seconds) in microgravity or which are test runs of experiments that will later be performed for longer periods in an aircraft, rocket, or spacecraft.

Reduced-gravity aircraft are flown in parabolic arcs to achieve longer periods of microgravity. The airplane climbs rapidly until its nose is at an approximate 45-degree angle to the horizon. Then the engines are briefly cut back, the airplane slows, and the nose is pitched down to complete the parabola. As the plane traces the parabola, microgravity conditions are created for 20–25 seconds. As many as 40 parabolic trajectories may be performed on a typical flight.

Sounding rockets produce higher-quality microgravity conditions for longer periods of time than airplanes. An experiment is placed in a rocket and launched along a parabolic trajectory. Microgravity conditions are achieved during the several minutes when the experiment is in freefall prior to re-entering Earth's atmosphere.

A **space shuttle** is a reusable launch vehicle that can maintain a consistent orbit and provide up to 17 days of high-quality microgravity conditions. The shuttle, which can accommodate a wide range of experiment apparatus, provides a laboratory environment in which scientists can conduct long-term investigations.

A **space station** is a permanent facility that maintains a low Earth orbit for up to several decades. The facility enables scientists to conduct their experiments in microgravity over a period of several months without having to return the entire laboratory to Earth each time an experiment is completed.



Microgravity Research Division